A New "Natural Neighbor" Meshless Method for Modeling Extreme Deformations and Failure

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The objective of this project is to develop a fully Lagrangian analysis approach, based on a "natural neighbor" discretization technique, to model extreme deformation and failure for analyses such as earth penetration and dam failure. The method is related to finite elements, except that arbitrary polyhedral elements are defined by Laplace shape functions. A free Lagrange approach can then be exploited such that mesh connectivity is redefined on the fly to eliminate mesh tangling. No remapping of quantities will be required since they will be computed and stored at the node points. The method is more stable than SPH methods, is faster than EFG meshless methods and circumvents the advection required by ALE. The method will be effectively meshless (nodes, and not connectivity, will define the model) and will be incorporated into DYNA3D.

Project Goals

If successful, the new approach will provide an improved method for modeling extreme events. For example, since the method is fully Lagrangian, better descriptions of anisotropic material damage for concrete can be applied, whereas Eulerian/ALE techniques have difficulties with these models due to advection. Water spilling over the damaged dam could be modeled with this approach. SPH is also fully Lagrangian but has stability issues and isn't suitable for implicit type problems such as static gravity loading of a dam. Because it is "meshless," the approach could be used for applications where nondestructive evaluations are required, such as as-built weapons analysis or biomechanics. In short, a much larger class of problems could then be solved.

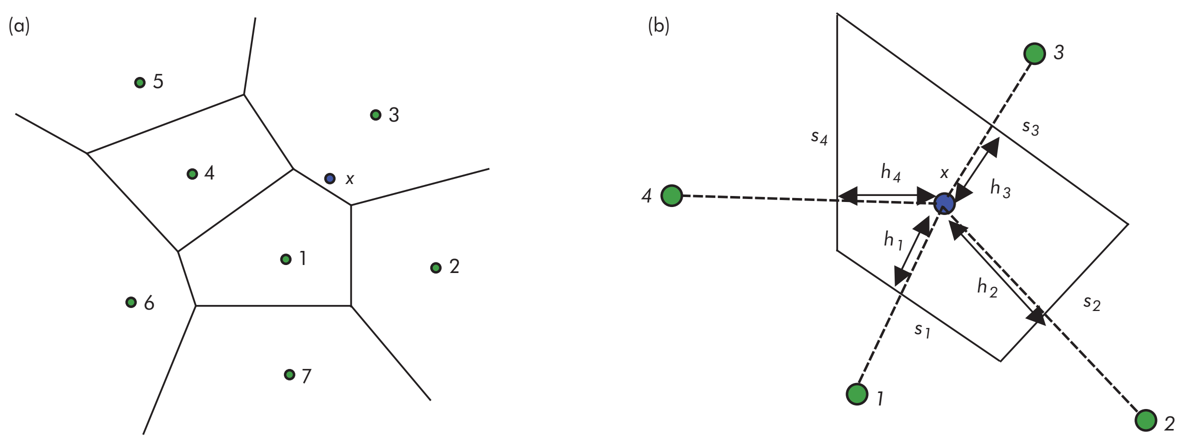

Figure 1. (a) Cloud of seven points and associated Voronoi diagram. Considering the arbitrary location, x, in (a), a secondary local Voronoi cell (b) can be formed about this location, x, using its "nearest neighbors," points 1 to 4.

Relevance to LLNL Mission

The proposed approach treats solid and fluid mechanics and is applicable to some important LLNL problems. Analyses of earth penetration, and terrorist vulnerability evaluation of infrastructures are target applications for this new approach. As-built x-ray tomography of NIF targets and *in-vivo* MRI imaging for biomechanics create "point clouds" and are good examples where some form of meshless method could be exploited for expediting stress analyses.

FY2004 Accomplishments and Results

In mid-FY2004, we began definition of data structures and code module development for the NIKE3D/DYNA3D implementation. This included the following tasks: 1) set up general, ragged-type data structures to handle arbitrary connectivity of a cloud of points; 2) implement Voronoi techniques for identifying nearest neighbors and discerning surface boundaries necessary for defining the integration domain; and 3) implement Laplace interpolation modules.

The natural neighbor method uses the Laplace shape functions defined from a Voronoi diagram of the cloud of points. Consider the 2-D cloud of points and the associated Voronoi diagram in Fig. 1 (a). The shape function N_i for node $i = 1,4$ evaluated at the location x, is computed from this local Voronoi cell in Fig. 1 (b) about the point x, using the length s_i (the length of the edge) and h_i (the distance between x and p_i) through the following equation:

$$N_i(\boldsymbol{x}) = \frac{s_i / h_i}{\sum_{j=1}^{5} s_j / h_j}$$

A stabilized nodal integration technique is then exploited to integrate the weak form of the equations of motion. In this approach, an average strain is computed at node i by integrating the strain field calculated from the shape functions, over the Voronoi cell of node i. By definition, the Voronoi diagram is unbounded and must be "trimmed" at the perceived surface boundaries (see Fig. 2). So, for example, the cloud of points in Fig. 3 (a) produces the "trimmed" Voronoi diagram in Fig. 3 (b).

We now have most of the parts of a serial implementation in NIKE3D completed.

FY2005 Proposed Work

FY2005 will be dedicated to finishing the NIKE3D/DYNA3D small deformation implementation and extending the work to handle large deformations and damage. Tasks include further evaluating different approaches for determining surface definition from a cloud of points; evaluating the free Lagrange approach for doing large deformations; and exploring different damage models.

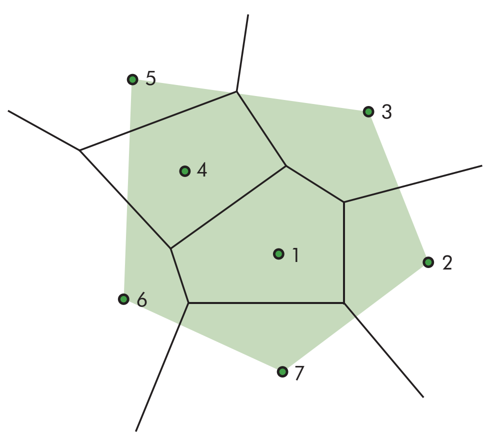

Figure 2. Unbounded Voronoi diagram "trimmed" by perceived surface boundaries. Shaded area defines integration domain for weak form of equations of motion.

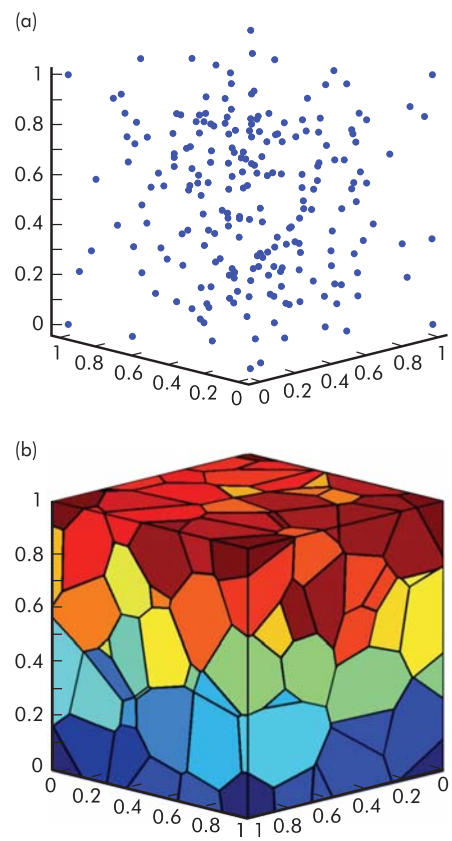

Figure 3. (a) Cloud of 216 points. (b) Voronoi diagram trimmed by surface definition.